Hierarchical Optimization
For Complex Shape Design

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Abstract

Methods for modification of complex aerodynamic configurations suffer from several drawbacks in current shape optimization efforts. The use of parametric Computer Aided Design (CAD) software allows for global or local shape perturbation, but requires manual identification of all design variables. Bump functions allow for local shape perturbation, but lead to extremely large and noisy design spaces.

The purpose of this research is to pursue optimization of complex configurations through an automated, level-of-detail approach. Splines are used to approximate the structure of a given geometry using an arbitrary number of control points. The geometry is then redefined in relation to this underlying structure. Combining geometry definitions using an increasing number of control points allows shape optimization to be performed in a hierarchical manner.

Method Overview

Goal: Parameterize & modify complex shape by redefining geometry in terms of reduced-order structure preserving spline approximation (SPSA).

Step 1: Import Complex Geometry
Ex: NASA SC(2)-0714 supercritical airfoil

Step 2: Coarsen to SPSA$^1$ control net

Step 3: Fit SPSA$^1$ as quasi-interpolant

Step 4: Calculate Displacement Map

Step 5: Perturb SPSA$^1$ Control Points

Step 6: Rebuild Geometry

Hierarchical Optimization

Global vs. Local Control:
Knot insertion in SPSA$^1$ allows for shape control with arbitrary number of degrees of freedom. Note this is not a reduced order representation of the geometry, but allows for multiple modification modes.

Sample Problem

Problem: Maximize lift to drag ratio for given airfoil at low Mach number and zero angle of attack.

Objective Function Evaluator: XFOIL
DV 1: x location of top spline control point
DV 2: y location of top spline control point
Optimizer: SQP optimizer with finite difference gradient approximation
Result: ~4x increase of lift to drag ratio

3 Dimensional Case

It is possible to extend this approach to three dimensions by using a class of splinar surfaces that offer efficient parameterization and representation of geometries of arbitrary topology.

Structural Modification
Complex Geometry Modification$^3$

Future Work

Methods for hierarchical geometry modification are well established, however, these methods have not been widely employed in numerical shape optimization. Future work will primarily focus on analysis of convergence properties of this hierarchical approach to numerical shape optimization.

Notes:
(1) Structure Preserving Spline Approximation (SPSA)
(3) This work is funded by a grant through NASA Ames